Change Detection Analysis (1986–2002) of Vegetation Cover in Romania

Authors: Mihai, Bogdan, Savulescu, Ionut, and Sandric, Ionut

Source: Mountain Research and Development, 27(3) : 250-258

Published By: International Mountain Society

URL: https://doi.org/10.1659/mred.0645

Mountain Research and Development Vol 27 No 3 Aug 2007: 250–258 doi:10.1659/mred.0645

Bogdan Mihai, Ionut Savulescu, and Ionut Sandric

Change Detection Analysis (1986–2002) of Vegetation Cover in Romania

A Study of Alpine, Subalpine, and Forest Landscapes in the Iezer Mountains, Southern Carpathians

The Iezer Mountains are part of the Southern Carpathians in Romania; the elevation range spans over 1800 m, with the highest peak at 2470 m. In recent years, the vegetation in this montane landscape has undergone various changes. The aim of the present analysis is to test whether the evolution of vegetation zones can be modeled using remote sensing data and official forestry cadastre data, in correlation with climatic data for the same period. Our analysis used the change detection procedure (image difference) with 2 LANDSAT TM/ETM+ subscenes for the summers of 1986 and 2002. Field research (2001–2005) helped us to validate thematic classification of the altitudinal zones. The change detection image showed general trends: an increase in timberline elevation, a gradual replacement of coniferous forests by mixed forests, and a natural regeneration of beech trees on mountain slopes.

Keywords: *Iezer Mountains; vegetation zones; LANDSAT satellite scenes; change detection; Carpathians; Romania.*

Peer-reviewed: *November 2006* ***Accepted:*** *March 2007*

Introduction

International documents such as *Agenda 21* highlight the vulnerability of mountains within the context of recent climate change (Beniston 2000, 2003). Hamilton et al (1999) and Beniston (2000) consider altitudinal zonation of mountain vegetation and the biodiversity of these zones to be sensors that indicate climatic and environmental change. This can be the subject of climate and environmental change models and scenarios (Beniston 2003). Another issue in mountains is overexploitation in light of the high potential energy of these environments (Delannoy and Rovéra 1996). This is an important issue in Eastern Europe, where radical socioeconomic change in the past 2 decades has influenced the way in which natural resources are used (Parvu 2001).

Mountain landscapes have long been an area of interest for remote sensing specialists. Multitemporal landscape analysis based on satellite imagery is one of the leading methods for analyzing environmental change in mountains (Haynes-Young 2000). In Eastern Europe, a synthetic approach considering land cover on the basis of the CORINE land cover classification system was taken by Feranec et al (2000), who also considered land cover dynamics of 3 variables (arable land, wetlands, and forests) in Romania between 1976 and 1991. More research on land cover dynamics in Romania's mountain areas is needed in light of the significance of vegetation—and forests in particular—in the context of global change (Körner et al 2005).

The present approach aimed to analyze the spatial evolution of forested areas in the context of human and natural environmental change in the Southern Carpathians. According to the official forestry cadastre, natural forest canopies represent about 35% of the total afforested area in the study area. This situation is not frequent in the Romanian Carpathians and investigation of zonation changes started from this reality. The main tasks were to validate remote sensing modeling of these phenomena using various sets of spatial data (official forestry cadastre maps, climatic data, and surveys from fieldwork), and assess the dynamics of change observed for the period of 1986–2002.

The region

The Iezer Mountains lie in the eastern part of the Southern Carpathians, in central to southeastern Romania (Figure 1). The relief index of this mountain region is 1820 m, with a minimum elevation of 650 m asl, while the highest point is 2470 m (Mount Rosu). The main mountain ridge orientation is SW to NE. The lithology of the Iezer Mountains consists of about 80% crystalline schist. A massive relief, old planation surfaces (from the Palaeogene and the Miocene), and a Pleistocene glacial morphology are the main morphological features. Sedimentary rocks also occur on the southern, southeastern, and eastern sides, together with some limestone, conglomerates, sandstones, marls, and clays.

The Southern Carpathians have a temperate mountain climate. The middle mountain climate extends from around 650–800 m to 1850–1900 m; the high mountain climate (above 1850–1900 m) is humid and cold. Air temperatures vary between 7°C and –2°C above 2100 m. Generally, the relief accounts for differences between rainfall on the western and northwestern slopes (where it is higher) and on the eastern and southeastern slopes. Along the southern border of these mountains, the average rainfall is 800 mm/year, while at higher elevations it is about 1200 mm. These environmental conditions have influenced the vegetal altitudinal zones in the Iezer Mountains:

- Alpine zone (> 2200–2250 m): meadows associated with *Carex curvula, Festuca supina, Juncus trifidus,* etc.
- Subalpine zone (from timberline to 2000–2250 m): dwarf pine (*Pinus mugo*) associated with juniper

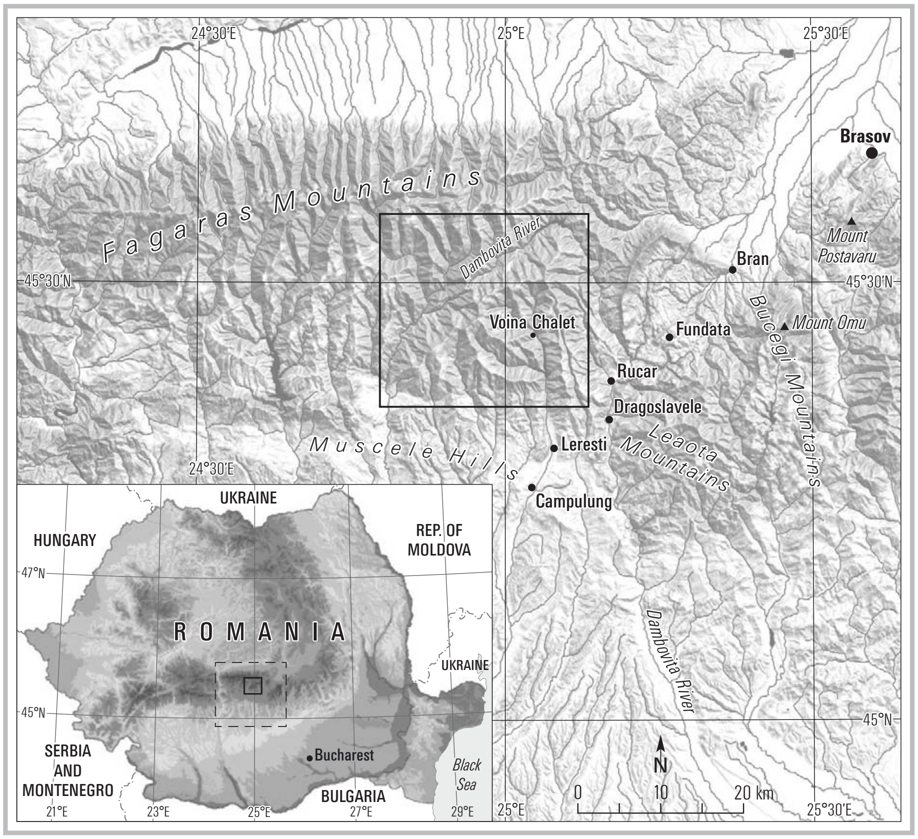


FIGURE 1 Location of the Iezer Mountains in the Southeastern Carpathians, Romania. (Shuttle Radar Topographic Mission, 2000; Digital Elevation Model by authors)

(*Juniperus nana*), *Vaccinum myrtillus*, *Vaccinum vitis idaea*, *Nardus stricta*, *Festuca supina*, etc.

- Coniferous forest zone (from 1300–1400 m to around 1800 m): in locally favorable climates the timberline extends above 1860 m, and on the southern aspect these forests start above the 1500-m contour line owing to the impact of centuries of grazing. Spruce (*Picea abies*) and silver fir (*Abies alba*) also occur.
- Deciduous forest zone (< 1300–1400 m): dominant beech (*Fagus silvatica*), with birch (*Betula pendula*) and hornbeam (*Carpinus betulus*).

Methods and materials

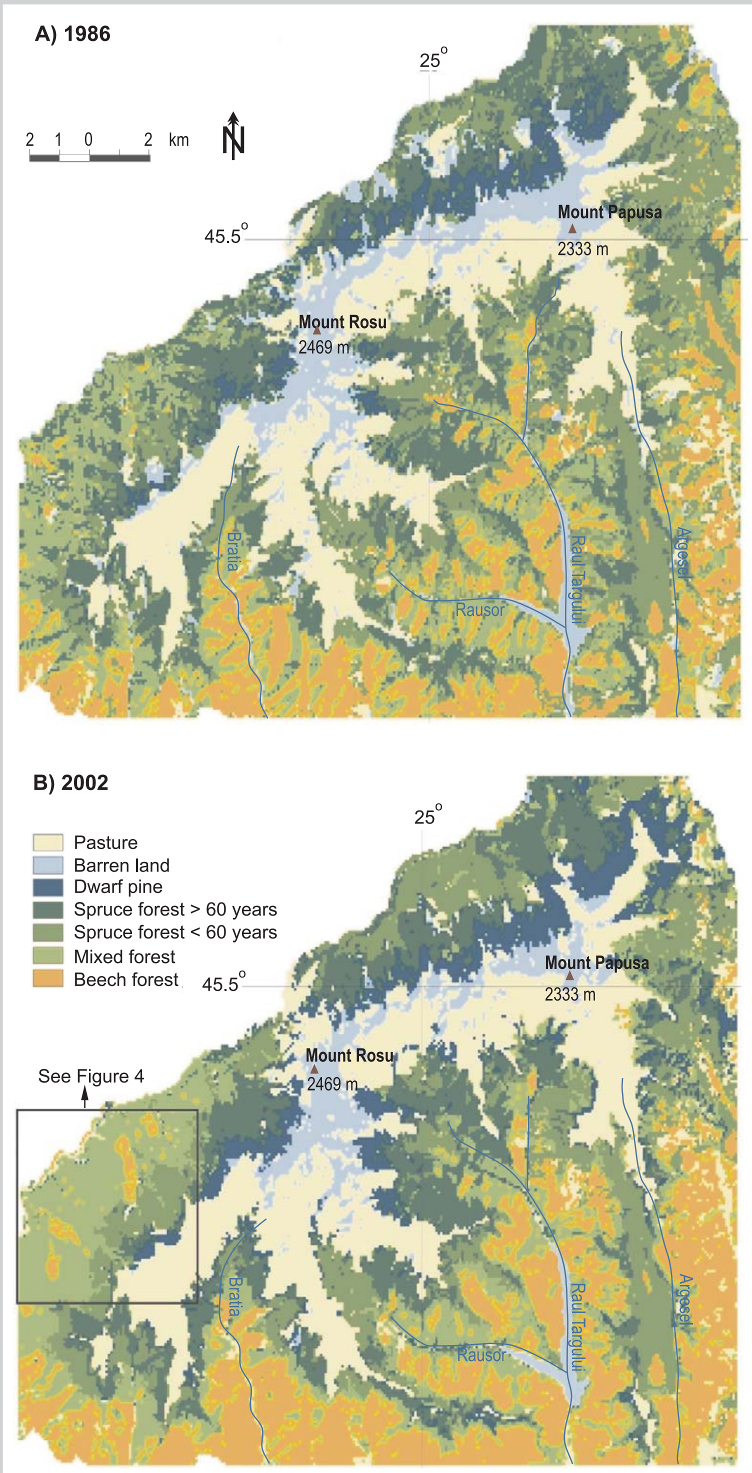
Changes in vegetation patterns were detected using LANDSAT TM and ETM+ imagery, owing to their good spectral and temporal resolution and moderate spatial resolution (Lillesand et al 2004; Short 2004), and accessibility in terms of price. Various authors have used multispectral LANDSAT satellite imagery to detect change in vegetation and land cover patterns (Millette et al 1995; Rigina et al 1999; Toutoubalina and Rees 1999; Woodcock et al 2001; Rees et al 2003; Tømmervik et al 2003).

Satellite data available were adapted to the surface of the study area (> 500 km^2), which is the most representative section of the Iezer Mountains. First, 2 satellite scenes (June 1986, LANDSAT TM; and June 2002, LANDSAT ETM+) were acquired for a similar season (summer, with mature vegetation and intensive grazing on subalpine and alpine pastures), and 2 sub-scenes (University of Maryland, Global Land Cover Facility 2003) were extracted and co-registered. Visual interpretation of the color composite (RGB=542) showed low cloud occurrence on these scenes—an encouraging factor, as this period is the rainiest in the Southern and Curvature Carpathians (30–40% of the total annual average rainfall occurs from June to July at 1000 m).

A second stage of analysis was topographic effect control. Shading is the main problem in using satellite imagery for classification purposes in high mountain areas (Millette et al 1995). Our study area was no exception; the scene was scanned at about 7:30 am. A Digital Elevation Model (DEM) at a grid resolution of 10 m had previously been generated. Basic data came from topographic maps at a scale of 1:25,000—the only ones available in analogical format (Gauss-Krüger projection, Krasovsky ellipsoid). The DEM was derived from a complete contour line vectorization on the 1:25,000 topographic maps (10-m resolution). The primary DEM was generated after the interpolation of data in a grid system. The very dense primary stream network affected the continuity of the model's surface; we used a median filter to smooth elevational values on slopes and interfluves. The contour interval was 10 m and filtering gave an acceptable quality for the model. Using the IDRISI® hillshade control procedure for this model co-registered with the sub-scenes, the shading effect was eliminated and both images were corrected.

A hillshade of the grid was used to derive the shaded areas on slopes for acquisition time of the satellite scenes. We subtracted this image from the satellite sub-

FIGURES 2A AND 2B Altitudinal zones of vegetation in the Iezer Mountains in 1986 (A) and 2002 (B).



scene in false color 453. The final image was then compared with the image of topographic normalization obtained by band ratios (Jensen correction method; Millette et al 1995). Filtering was necessary to smooth the image and eliminate residual pixels of shaded areas. The good quality of the original scenes used simplified image enhancement procedures. Sensor calibration was performed previously, and filtering with a 3x3 kernel (smoothing, non-directional) was used to normalize the satellite image database. Both sub-scenes were brought to a similar histogram configuration for each spectral band (4, 5, and 3). Equal spectral resolution (IR, middle IR, red) and spatial resolution (28.5 m) allowed a good change detection procedure using simple algorithms (Sabins 1997; Lillesand et al 2004).

Supervised classification was based on different data sources. Field research began in June–July 2000, with a GPS survey (approximately 4 m precision) of test areas in all the vegetation zones of the Iezer Mountains. Points were recorded at different altitudes, sometimes using landmarks such as rock outcrops or topographic points on the ground. We checked selected points on the ground each year, during short campaigns in June, July, and September–October for every year between 2000 and 2004. The points recorded allowed precise drawing of the training areas for the supervised classification of vegetation on the LANDSAT multitemporal images.

A further GPS field survey was used to differentiate training areas for our classification (over 500 points). We focused on critical points along the limits of vegetation zones which were superposed on the satellite images. Timberline configuration was followed in track mode, in detail, to an accuracy of 6 m. Small forests (*rariste*, Romanian for "groups of isolated trees") and glades (*poiana*, or "pasture surrounded by forest") appearing within the main vegetation zones on both images were surveyed and classified. The location of barren land (rock outcrops, talus slopes, and cones) was controlled through fieldwork and GPS surveys. The results were compared with the official forestry authorities' maps for this region. These Forestry Cadastre Maps—made by the Institute of Forestry Research and Development (Institutul de Cercetari si Amenajari Silvice, ICAS) in Bucharest, on paper, at a scale of 1:20,000—contain relevant information about the limits of canopies, species, ages, and density of canopies, and are updated every 10 years. We converted the latest edition (1996) to digital format, and after geometric correction we extracted information in vector format.

A maximum likelihood classification was performed on normalized imagery. Using the differenced spectral response features of vegetation in a false color composite 453, the following 8 training areas were drawn for the sub-scenes:

- Secondary meadows (created by anthropogenic clearing);
- Alpine and subalpine pastures (difficult to differentiate at this spatial resolution);

TABLE 1 Change detection matrix for the 1986–2002 period.

1986 / 2002	Pasture	Barren land	Dwarf pine	Spruce forest	Mixed forest	Beech forest
Pasture		10.86	1.84	18.98	3.42	3.19
Barren land	5.48		0.26	1.18	0.13	0.03
Dwarf pine	5.73	4.81		1.70	0.10	0.01
Spruce forest	14.40	6.84	7.96		10.34	5.83
Mixed forest	3.31	2.35	0.02	38.46		17.60
Beech forest	4.66	2.16	0.03	12.13	20.95	

- Barren land (no-vegetation areas on rock outcrops and erosion-affected land, steep slopes in glacial cirques and troughs, talus slopes);
- Dwarf pine associations (checked through GPS survey);
- Spruce forests older than 60 years (checked against forestry authority documents and through GPS field surveys);
- Spruce forests younger than 60 years (checked against forestry authority documents and through field mapping);
- Mixed beech, spruce, and silver fir forests;
- Beech forests.

An error matrix was computed through a randomly selected cluster check, with 100 control areas selected in different vegetation zones. The results were encouraging (total accuracy was about 91%). All of these training areas cover the main land cover classes in the Iezer Mountain landscape. They allowed us to obtain digital data layers for application of the change detection procedure, using the image difference formula (1):

$$I = S2 - S1 \quad (1)$$

where I is the change detection image, S2 the second stage classification image for June 2002, and S1 the first stage classification image for June 1986.

This simple difference method was preferred because of the good class differentiation by number of pixels and low noise level in the framework of the radiometric features (Figures 2A and 2B). A new map was computed and registered to the local toponyms for purposes of interpretation. This is the change detection image for this area between 1986 and 2002. Some of the classes were mapped as unitary as the result of image resolution and scale (eg meadows).

In order to explain the evolution of vegetation zones, we took the opportunity to integrate certain climatic data in our case study. We selected 3 weather stations close to our area of interest, as there is no facility within the Iezer Mountains (see Figure 1). Mount Omu weather station in the Bucegi Mountains (2504 m) is representative of the alpine and subalpine zones. Fundata weather station (1384 m) features spruce and beech mixed forests, while Campulung weather station (681 m) is representative of the border of the Iezer Mountains. The average annual temperature data for the reference time series (June 1985 to June 2000) were computed in a linear regression graph for each of these 3 weather stations.

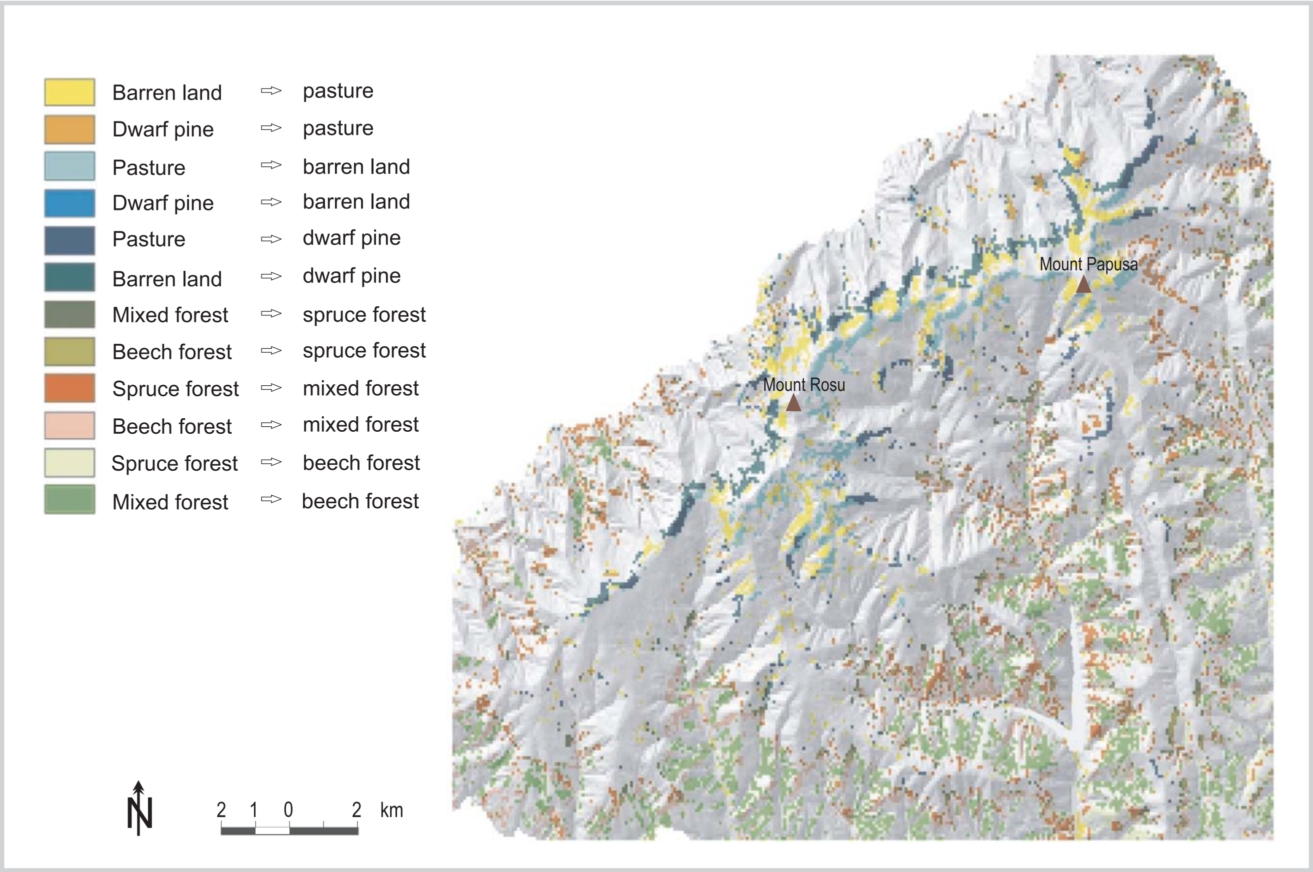
Results

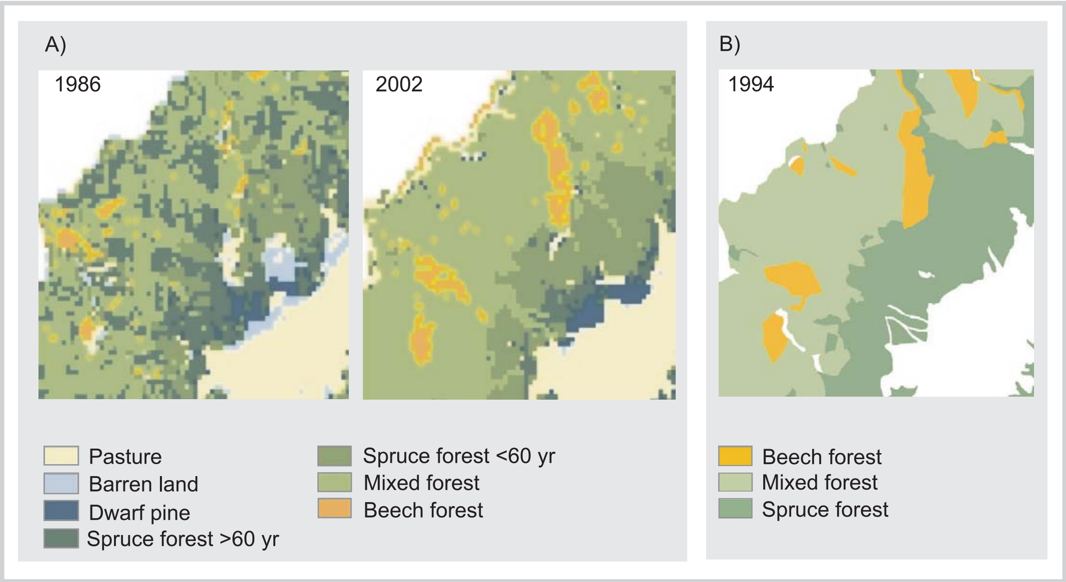
The results of change detection analysis were included in a chart showing class changes from 1986 to 2002 (Table 1). To explain these transformations after validation through fieldwork, the statistical approach was related to the final change detection map (Figure 3), which offers an overview of the transformation areas for the 1986–2002 reference period, using darker tones for the most spectacular changes. The resulting map was not filtered, because the scattered points confirm the replacement of spruce communities by beech communities, a common process in the Romanian Carpathians.

Given the size of the study area (> 500 km^2), it was not possible to produce a detailed map of transformations at the chosen resolution of 30 m. The visualization we present here is at a large scale, but for areas that showed the most evident evolution, selected for their complementarity, we studied details at a small scale. These areas reflect different situations (Figure 4 is one example), ultimately portraying the situation throughout the study area.

Statistics first make it possible to certify actual colonization by vegetation of the subalpine and alpine rock outcrops and talus slopes by grasses (Table 1). Between 1986 and 2002, more than 10 km^2 of barren land were covered with soil, pioneer vegetation, and pasture. This is a feature of debris slopes on the northern aspect, where gradients of more than 20–30° limit grazing and

FIGURE 3 Change detection image of vegetation zones in the Iezer Mountains, with hillshade. The darkest clusters correspond to the most spectacular changes in vegetation zones.





FIGURES 4A AND 4B Detailed view of a typical pattern of change observed: beech forest replaces coniferous forest on northwestern slopes. Thematic supervised classification subsets (A) and official forestry cadastre map (B); on this latter map, dwarf pine is included in "spruce." (Source of (B): ICAS 1994)

other activities, including tourism (hiking). By contrast, only 5.48 km^2 were transformed from pasture to barren land. These lands cover slopes on the southern aspect, where grazing starts earlier (May) and sheepfolds have developed for centuries on flat planation surfaces. Avalanche paths and deeper ravines regularly destroy soil and vegetation cover on southern slopes.

Dwarf pine (*Pinus mugo*) subalpine associations developed and gradually covered subalpine meadows and barren land. Between 1986 and 2002, dwarf pine colonization averaged 0.14 km^2/year, or about 1.4 km^2/decade. This might be important in the context of the surface of the subalpine and alpine zones in the Iezer Mountains (116 km^2). Dwarf pine area lost terrain

FIGURE 5 Dwarf pine colonizing talus slopes in patches and steep slopes in Piscan Cirque. (Photo by Ionut Savulescu, 2004)

because of the spruce forests (ca 8 km^2), which increased in elevation. This is largely a feature of southern aspect slopes (sunny), where the natural timberline is, under some local conditions, higher than 1850 m, as in the Fagaras Mountains, situated in the northern neighborhood (Voiculescu 2002; see Figure 1).

Grazing ceased in some areas (Piciorul Iezerului), sheepfolds closed, and natural forest regeneration started affecting steeper slopes (10–20°). Gullies and ravines have disappeared in some upper catchments in this area. Vegetation has also begun to develop on the slopes of gullies and ravines, eventually covering the thalwegs. The evolution rates of these landforms decrease until they reach a state of equilibrium. These landforms are no longer visible in satellite imagery or aerial photos under recent colonization by vegetation.

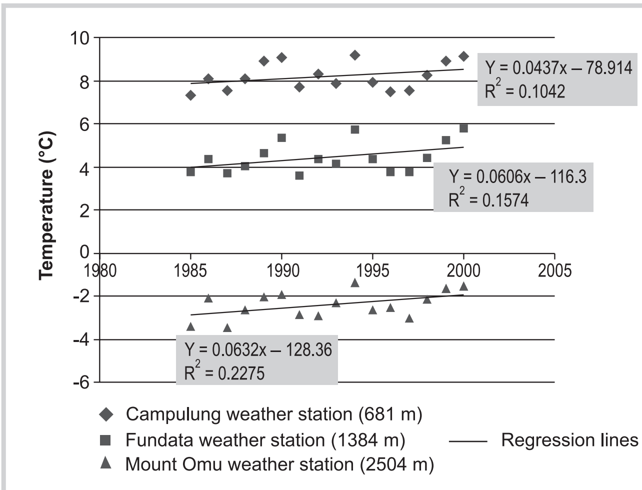
By comparison, colonization of barren land by dwarf pines took place at a rate lower than 0.06 km^2/year. These lands can be compared with talus slopes, such as those found in glacial cirques, in areas where the occurrence of snow patches (Figure 5) and even ice core talus deposits with sporadic permafrost structures takes longer (Urdea 1995; Szepesi 1998, 1998–1999).

The coniferous forest zone has a general tendency to increase in elevation. This belt has won the competition against dwarf pines, with an average growth of 6.2 km^2 in 16 years. Generally speaking, dwarf pine forest (*Pinus mugo*) actually lost a total surface area of 27.4 km^2 under pressure from lower vegetation communities such as mixed beech, spruce, and silver fir forests, beech forests, and even secondary pastures. Secondary meadows, important for grazing, replaced coniferous forests on 4.5 km^2, especially around the timberline area. Rather than recovering, spruce was mostly harvested during the reference period. Human impact from grazing, especially on the southern, sunny sides of the mountain (the "mountain face") halted spruce development on flat planation surfaces. This is the reason for the low level of transformation of the timberline on southern slopes. All the ridges are divided between sheepfolds and shepherd huts (*stane*); grazing, which had its apogee in the 18th and 19th centuries, is still a basic activity of the Ungureni population in the Muscel area (Osaci-Costache 2004).

The most remarkable feature of coniferous forests is their gradual replacement by mixed forests (see Figure 4), which increased by 28.1 km^2, possibly as a result of the worldwide trend in the altitudinal development of forest zones (Beniston 2000). Forest growth is also the result of the protection function of the forest along roads or around reservoirs and settlements/chalets (Rausor Lake, along the Raul Targului River, Voina chalet, Leresti, Rucar and other big villages).

Beech forests are the most dynamic by comparison with spruce forests (6.3 km^2) and mixed forests (3.4 km^2), and by comparison with barren areas and

FIGURE 6 Mean annual temperature for the 1985–2000 period, showing a general warming trend, which could partially explain the dynamics of the vegetation zones.



secondary meadows (together representing 3.6 km^2). This might be related to general natural recovery of beech on deforested slopes, as we have already observed in other mountain areas. For example, in the Postavaru Mountains (1799 m), in the northeastern wards, located at about 50–60 km from Iezer, we observed very good *Fagus silvatica* recovery on talus cones and along some old footpaths around the town of Rasnov (Mihai 2005). Protection forests around settlements (Leresti, Dragoslavele, and Rucar) have also colonized previous pastures and hayfields. Former gullies along cart roads and footpaths have disappeared under beech forests in the context of recent agricultural stagnation in mountains.

Discussion

The results of our classifications consist of 2 raster layers corresponding to the vegetation zonation for 2 reference moments (1986 and 2002). Markov probability models (Lopez et al 2001) were implemented with both images for a reference time of 16 years, equal to the multitemporal image interval. Computation with the IDRISI® probabilistic module made it possible to establish a prognosis of future evolution of forest altitudinal zones. The new raster layer does not reflect spectacular evolution because the reference period was short. There are many clusters showing different trends from one mountain ridge to another, and these cannot be interpreted easily. The only conclusion is that dwarf pine will colonize talus slopes and beech will be in competition with spruce.

The main results of our case study confirm the results of previous research on mountain vegetation zones. According to Hamilton et al (1999), there is a general trend for mountain geoecological belts to increase in altitude, especially in areas with good ecological conditions. This phenomenon exhibits different intensities from mountain to mountain, and is a subject for future research. Dullinger et al (2003, 2004) have explained the role of geoecological conditions on each mountain ridge, which control competition among vegetation species in the timberline area. Research in the Austrian Alps (Dullinger et al 2003) has shown real competition between grassland and dwarf pine communities, which could also be driven by shifts in climatic conditions.

In the Romanian Carpathians, various studies (Balteanu 2000; Geanana 2004) have confirmed the colonization of debris slopes and talus cones. In the Polish Tatras this trend was confirmed a long time ago by Plesnik (1971) and recently by Kotarba (2005). Mihai (2005) investigated the dynamics of forest cover in the Postavaru-Piatra Mare Mountains (ca 50 km northeast of the Iezer Mountains). The results of the GIS comparison between a SPOT High Resolution Visible (1997) and the topographic maps (1:25,000, since 1982) confirmed an increase of a few hectares of afforested area. Ground validation in August–September 2002 confirmed strong recovery of beech trees on talus cones and along older, unused tourist trails. Some trails shown on 1989 tourist maps no longer existed in 2002 (only signs on trees remained).

As we observe in Figure 6, there is a smooth general increase in temperature, which could partly explain the transformations in forest vegetation. Humid and cool weather canopies (coniferous) are replaced by mesophillic canopies (deciduous). But these changes also occur in a mountain area with long-established and still important human impacts that lead either to more or to less forest. This is related to easy access in this area along the valleys (by forestry roads connected to highways of national and European importance) as well as on the ridges (old and dense footpath networks). During the time when our study was carried out, the area was subjected to timber harvesting at different points (close to sheepfolds, near the timberline, on slopes after windthrows, etc). Hydrotechnical construction in the upper Raul Targului and Dambovita valleys also required forest clearing around dams and reservoirs. Grazing, in decline since the 1950s, still remains an important activity in some areas with old sheepfolds, situated in the same place since the 19th century. Forests therefore show evidence of strong human impacts and only a few areas are natural forests ("natural fundamental forests;" ICAS 1996). Only these remnants of natural canopies can be used as indicators of environmental change; this method can only explain land cover changes in this mountain area in a period of positive evolution of mean temperatures. This is not a coincidence, but in our study area, both climatic and anthropogenic factors were relevant and their effects cannot be separated, nor was this our aim.

The role of multispectral remote sensing imagery in mapping vegetation is well known. Multitemporal imagery improves the possibility of monitoring landscape transformation for a given period and for a given area. LANDSAT imagery has a big advantage over change detection analysis because of its larger temporal resolution. Interest is focused mainly on later generations (TM and ETM+), which have similar spatial and spectral resolutions. These satellite sub-scenes are useful for regional studies. Each pixel means a surface of about 900 m^2, which is not so important at a regional scale of one mountain unit. An approach that considers local features requires other sets of imagery, although their higher spatial or spectral resolutions are not sufficient. A time series must be established at an interval of no less than 10 years in order to be relevant. No large-scale imagery is available for temporal resolution greater than 6–7 years. Currently, only LANDSAT, SPOT, and ASTER can provide useful information for detailed change detection analysis of vegetation zones.

Data normalization processes are essential. Classification must use the same regions of interest in order to obtain accurate results. Cloud cover must be minimal, as there could be important loss of information and no-data clusters in classification and within the final map. Image differences might be replaced by classification image differences. This is necessary as a result of phenological shifting of the vegetation data, even if we use imagery from the same season. Image differences are easy to compute, which is easier to do using visualization rather than other methods, such as change vectors (Lillesand et al 2004). Permanent field recognition is essential for a successful and accurate result. This may go together with drawing of the classification test areas.

Conclusions

This case analysis took place in a small mountainous area in the Southern Carpathians representative of vertical zonation of landscapes. It is a part of the so-called "Transylvanian Alps" (De Martonne 1981), owing to its similarities with the subalpine mountain belt of the European Alp system. This mountain volume creates good conditions for elaborating scenarios of landscape dynamics (Hamilton et al 1999). On the scale of the Romanian Carpathians, the Iezer Mountains are notable for their "high and middle mountain" landscape and their environmental features (Muica et al 1981; Patroescu and Nancu 1995). The vertical zonation of their vegetation includes all the zones of the Carpathians. They can be easily differentiated in terms of limits, even with medium resolution multispectral imagery.

The main conclusion of this case study is that woody species have a general natural tendency to recover. Their limits change with altitude and their elevation has increased by about 25–50 m in only 16 years. This means an estimated rate of displacement of about 1.5 m per year. Grazing is an obstacle to forest invasion on planation surfaces. Its contribution to shaping the timberline configuration since the 18th–19th centuries is well known from old maps of Wallachia (Popp 1933). The situation characterizes almost all the mountains in the Southern Carpathians. Sunny slopes are perfect for these activities, as indicated by toponyms (*vacarea* coming from cattle grazing; Patroescu and Nancu 1995). Beech forest (*Fagus silvatica*, a typical Central European element of vegetation) is the most dynamic in this process. It is well adapted to this pedoclimatic background and follows a large "recovery corridor" along slopes. Small glades and timber harvesting areas within the forests and along slopes have disappeared in this process of vegetation recovery. Coniferous forests are increasingly losing ground and beech at some points is close to the upper tree limit (Voievoda Ridge).

Applying Markov's probability chain equations (Lopez et al 2001), no spectacular results were obtained. This means that the rate of evolution for the configuration of vegetation zones is low. The general trend is one of forest recovery in the secondary subalpine meadow zone. Eroded lands around sheepfolds are a barrier in this process. One of the reasons for forest recovery and rising timberline may be the climate warming trend of approximately 0.3°C/decade observed in neighboring meteorological stations.

An efficient sustainable forest management system is easy to develop in a mixed configuration. The climatic, hydrological, and soil protection functions of the forest are better preserved within these "more stable" ecosystems (against insects or diseases, for example). Single species forests are more vulnerable than mixed ones.

AUTHORS

Bogdan Mihai, Ionut Savulescu, and Ionut Sandric
University of Bucharest, Faculty of Geography, 1, N. Balcescu Blvd., 010041 Bucharest, Romania.
bogdan@geo.unibuc.ro; savulescui@yahoo.com; sandricionut@yahoo.com

REFERENCES

Balteanu D. 2000. Present-day geomorphologic processes and environmental change in the Romanian Carpathians. *In:* Balteanu D, Ielenicz M, Popescu N, editors. *Geomorphology of the Carpatho-Balkan Region.* Bucharest, Romania: Corint, pp 123–128.
Beniston M. 2000. *Environmental Change in Mountains and Uplands.* London, United Kingdom: Arnold.
Beniston M. 2003. Climatic change in mountain regions: A review of possible impacts. *Climatic Change* 59:5–31.
De Martonne E. 1981. *Cercetari asupra evolutiei morfologice a Alpilor Transilvaniei.* Bucharest, Romania: Academiei.
Delannoy J-J, Rovéra G. 1996. L'érosion dans les Alpes occidentales: contribution à un bilan des mesures et des méthodes. *Revue de géographie alpine* 84:87–101.
Dullinger S, Dirnböck T, Grabherr G. 2003. Patterns of shrub invasion into high mountain grasslands of the northern calcareous Alps, Austria. *Arctic, Antarctic and Alpine Research* 35:434–441.
Dullinger S, Dirnböck T, Grabherr G. 2004. Modelling climate change-driven treeline shifts: Relative effects of temperature increase, dispersal and invasibility. *Journal of Ecology* 92:241–252.
Feranec J, Suri M, Otahel J, Cebecauer T, Kolar J, Soukup T, Zdenkova D, Waszmuth J, Vijdea V, Vijdea AM, Nitica C. 2000. Inventory of major landscape changes in the Czech Republic, Hungary, Romania and Slovak Republic 1970s–1990s. *International Journal of Applied Earth Observation and Geoinformation* 2:129–139.
Geanana M. 2004. *Limita superioara a padurii in Muntii Retezat.* Bucharest, Romania: Editura Universitatii din Bucuresti.
Global Land Cover Facility. 2003. Global Land Cover Facility. *University of Maryland.* http://www.glcf.umiacs.umd.edu; accessed on 24 May 2007.
Hamilton LS, Gilmour DA, Cassels DS. 1999. Forêts et silviculture en montagne. *In:* Messerli B, Ives JD. *Les montagnes dans le monde. Une priorité pour un développement durable.* Grenoble, France: Glénat, pp 249–278.
Haynes-Young R. 2000. Teledetecţia modificărilor mediului înconjurător, Schimbări majore ale mediului. *In:* Roberts N, editor. *Schimbari globale ale mediului.* Bucharest, Romania: All, pp 20–38.
ICAS [Institutul de Cercetari si Amenajari Silvice]. 1994. *Amenajamentul Ocol Silvic Domnesti—Unitatea Productie II Corbi, Unitatea Productie IV Papau.* Bucharest, Romania: ICAS.
ICAS [Institutul de Cercetari si Amenajari Silvice]. 1996. *Amenajamentul Ocol Silvic Campulung—Unitatea Productie I Campulung, Unitatea Productie II Bughea, Unitatea Productie III Leresti, Unitatea Productie IV Rausor, Unitatea Productie V Voina, Unitatea Productie VI Argesel.* Bucharest, Romania: ICAS.
Körner C, Ohsawa M, et al. 2005. Mountain systems. *In:* Millennium Ecosystem Assessment. *Current State and Trends: Findings of the Condition and Trends Working Group. Ecosystems and Human Well-being*. Vol 1, Chapter 24. Washington, DC: Island Press, pp 681–716.
Kotarba A. 2005. Geomorphic processes and vegetation pattern changes case study in the Zelené Pleso valley, high Tatra, Slovakia. *Studia Geomorphologica Carpatho-Balcanica* 39:39–48.
Lillesand Th, Kiefer R, Chipman JW. 2004. *Remote Sensing and Image Interpretation.* New York: Wiley.
Lopez E, Boco G, Mendoza M, Duhan E. 2001. Predicting land-cover change in the urban fringe. A case study in Morelya City, Mexico. *Landscape and Urban Planning* 55:271–285.
Mihai B. 2005. *Muntii din bazinul Timisului. Potential geomorfologic si amenajarea spatiului montan.* Bucharest, Romania: Editura Universitatii din Bucuresti.
Millette Th, Tuladhar AR, Kasperson RE, Turner BL. 1995. The use and limits of remote sensing for analyzing environmental and social change in the Himalayan Middle Mountains of Nepal. *Global Environmental Change* 5:367–380.
Muica C, Patroescu M, Popova-Cucu A. 1981. Tipuri de mediu din Carpatii Romanesti. *Analele Universitatii Bucuresti, Seria Geografie* 30:99–108.
Osaci-Costache G. 2004. *Muscelele dintre Dambovita si Olt in documente cartografice.* Bucharest, Romania: Universitara.
Parvu C. 2001. *Ecologie generala*. Bucharest, Romania: Editura Tehnica.
Patroescu M, Nancu D. 1995. Influences anthropiques sur les limites des étages de végétation des Monts Iezer (Carpates Méridionales). *In:* Badea L, editor. *Geographical International Seminar, No. 3*. Bucharest, Romania: Institutul de Geografie al Academiei Romane, pp 29–31.
Plesnik P. 1971. *Horna hranica lesa vo Vysokych a v Belanskych Tatrách.* Bratislava, Slovakia: Veda.
Popp M. 1933. Contributiuni la vieata pastorala din Arges si Muscel. *Buletinul Societatii Regale Romane de Geografie* 52:229–282.
Rees WG, Williams M, Vitebski V. 2003. Mapping land cover change in a reindeer herding area of the Russian arctic using Landsat TM and ETM+ imagery and indigenous knowledge. *Remote Sensing of the Environment* 85:441–452.
Rigina O, Baklanov A, Hagner O, Olson H. 1999. Monitoring of forest damage in the Kola Peninsula, Northern Russia due to smelting industry. *The Science of the Total Environment* 229:147–163.
Sabins FF. 1997. *Remote Sensing. Principles and Interpretation.* New York: Freeman.
Short NM. 2004. The remote sensing tutorial. *NASA. Goddard Space Flight Center.* http://rst.gsfc.nasa.gov; accessed on 26 November 2005.
Szepesi A. 1998. *Muntii Iezer. Studiu fizico-geografic cu privire speciala asupra proceselor de modelare actuala.* [PhD thesis abstract]. Bucharest, Romania: University of Bucharest.
Szepesi A. 1998–1999. Exista permafrost în Masivul Iezer? *Studii si Cercetari de Geografie* 45/46:51–60.
Tømmervik H, Høgda KA, Solheim I. 2003. Monitoring vegetation changes in Pasvik (Norway) and Pechenga in Kola Peninsula (Russia) using multitemporal Landsat MSS/TM data. *Remote Sensing of the Environment* 85:370–388.
Toutoubalina OV, Rees WG. 1999. Remote sensing of industrial impact on Arctic vegetation around Noril'sk, northern Siberia: Preliminary results. *International Journal of Remote Sensing* 20:2979–2990.
Urdea P. 1995. Quelques considérations concernant des formations de pente dans les Carpates Méridionales. *Permafrost and Periglacial Processes* 6:195–206.
Voiculescu M. 2002. *Studiul potentialului geoecologic al Masivului Fagaras si protectia mediului inconjurator.* Timisoara, Romania: Mirton.
Woodcock C, Macomber S, Pax Leney M, Cohen W. 2001. Monitoring large areas for forest change using LANDSAT: Generalization across space, time and LANDSAT sensors. *Remote Sensing of the Environment* 78:194–203.